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Sustainable use of natural resources for crop intensification and better livelihoods in the rainfed semi-arid tropics of Central India

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ABSTRACT

In Indian semi-arid tropics (SAT) in general and central part i.e. Madhya Pradesh state specifically; there are large yield gaps in most of the rainfed crops between current farmers' yields and achievable ones. Soil fertility related degradation due to deficiencies of secondary and micronutrients mainly sulphur, boron and zinc in addition to macronutrients is mainly responsible for poor crop productivity, and along with poor hydraulic properties of Vertisols is responsible for about 2 million ha rainy season fallows. Soil health assessment of 11 districts in Madhya Pradesh, India has revealed that in most of the districts only few fields with adequate levels of sulphur, boron, zinc and phosphorus indicating their widespread low levels. Potassium was in general adequate. Farmers' current blanket fertilization practices focused at macronutrients viz. nitrogen, phosphorus and potassium only, thus does not meet the variable soil fertility needs. Through participatory action research on soil test based fertilizer application, farmers realized benefits in crop productivity to the tune of 5 to 45% in the season of application and additional yield by 5 to 27% due to residual effects of S, B and Zn in succeeding three seasons. An economic assessment showed the balanced nutrition a profitable option in the 1st season itself. In current rainy fallow regions, the landform management as broadbed and furrow or conservation furrow along with balanced nutrition has shown that fallow lands in black soil regions in Madhya Pradesh can be successfully cultivated to grow soybean crop. In succeeding post-rainy season, the rainy season cultivated plots also yielded more as compared to adjoining plots having one crop only in post-rainy season. This study thus found that soil test based fertilization and landform management are the twin technologies for sustainable crop intensification in black soils of Central Indian region.

1. Indian rainfed semi-arid tropics (SAT) – importance and issues

Eighty per cent of the cultivated area worldwide is rainfed and contributes nearly 60% of the world's food [1]. These are the homes to world's poor and malnourished people, and maximum population growth (95%) is taking place in these developing regions [1]. In India also, the rainfed cropped areas comprise about 60% i.e. 89 million ha [2]. The 40% of irrigated area in India has reached a plateau in terms of productivity and today there is a big issue of concern to feed the burgeoning population. Irrigation expansion, a major thrust of growth in crop area in the past decade, is likely to continue and irrigation coverage is expected to increase from 40% to 55% over the period 2000–2050, thus still around 45% of the area in the year 2050 will continue to remain rainfed [3,4]. The option of increasing arable land is exhausted and rather per capita arable land availability in India has decreased from 0.39 ha in 1951 to 0.12 ha in 2011 due to increased population from 359 million in 1951 to 1.21 billion in 2011 [5], which is further expected to rise to 1.69 billion by 2050 [6] with associated decrease in per capita land availability (0.09 ha). Within existing land and water constraints, India must sustainably increase the current food production to around 380 million t in 2050 [4], to meet the growing food demand. So, in current context, it is very necessary to increase the productivity levels of the major rainfed crops to meet the ever-increasing demand of food, which emphasize the critical importance of rainfed agriculture in Indian economy and food security. Moreover it is a well-established fact that agriculture plays a key role in economic development [7] and poverty reduction [8] which is a rampant problem in Indian

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rainfed SAT regions. There is evidence indicating that every 1% increase in agricultural yields translates to a 0.6% to 1.2% decrease in the percentage of absolute poor [9], and so the issue of agriculture development in neglected rainfed regions assumes much more importance today than ever before.

Madhya Pradesh in India is a typical semi-arid tropical region. Agriculture is the predominant occupation and source of livelihood for rural people, and therefore natural resource base is the lifeline of the millions of rural poor. Depletion of the resource base is diminishing the capabilities of poor farmers to earn more and making them vulnerable to drought and other climate related disasters. The present scenario so clearly points to the need for adoption of science-led interventions leading to efficient and sustainable use of natural resources to improve agricultural productivity and livelihoods to alleviate poverty, hunger and malnutrition in SAT regions of Madhya Pradesh and India.

2. Important rainfed crops in SAT regions in Madhya Pradesh, India

In cropping pattern of Madhya Pradesh, soybean (*Glycine max* (L.), groundnut (*Arachis hypogaea* L.) and mustard (*Brassica compestris*) are the major oilseed crops (Table 1). For the country as such, soybean and groundnut together contributing about 64% of total oilseed production [5]. As regards to soybean, Madhya Pradesh is the state contributing largest acreage (56%) and production (51%) at national level (Table 1). Being the cheapest source of high quality protein (40%) [3], soybean has potential to play an important role in mitigating the large-scale problem of protein malnutrition particularly in children and women in the rural areas of the country. Its oil content (18%) is second only to groundnut among food legumes [3]. Low soybean productivity in the state in comparison to even at national level in spite of suitable agro-climatic conditions is a matter of concern. Groundnut is important oilseed crop in India (5.31 million ha area, 6.93 million tonnes production) and Madhya Pradesh state contributes significantly about 4% of national acreage and about 5% of national production (Table 1). Groundnut seeds contain high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%) [3]. Both soybean and groundnut are legume crops which help in improving soil health, and hence have an important role in fitting in the cropping system mainly during the rainy season and sustaining soil fertility in the drylands.

Among pulse crops, chickpea (*Cicer arietinum* L.) is one of the most important crops of India contributing about 44% of total pulse production, and Madhya Pradesh state contributes highest (37%) to nation chickpea acreage and national chickpea production (43%) (Table 1). In low input traditional production systems, chickpea has been a preferred crop because of its minimal dependence on monetary inputs of N and P-containing fertilizers, irrigation and agrochemicals in general. It is a valuable source of protein for poor population and a source of livelihood for the small and marginal farmers in India and other developing countries. Chickpea is a suitable legume crop to fit in the cropping system during post-rainy season and thus contribute soil health improvement and sustaining soil fertility particularly in drylands.

As regards cereals, wheat (*Triticum aestivum*), maize (Zea mays), rice (Oryza sativa) and coarse cereals fit in the cropping system in Madhya Pradesh, and their lower productivity (Table 1) mainly due to poor management is an issue of concern. Wheat is cultivated during post-rainy season and Madhya Pradesh is next to Uttar Pradesh in acreage and Uttar Pradesh, Punjab and Haryana in production [5]; and contributes to about 16% of national acreage and 11% of national production (Table 1). Wheat yields in different states vary tremendously due to different technologies adopted by the farmers and the agro-climatic characteristics of the region.

3. Large yield gaps and existing potential to tap in the rainfed SAT regions in India

Despite long history of cultivation along with being important source of livelihood and nutrition for the small and marginal farmers in Madhya Pradesh, and SAT regions in India, the actual yields from rainfed agriculture have remained quite low as compared to achievable ones[10–15]. Historic trends present a growing yield gap between farmers' practice (FP) and farming systems that benefit from management advances. Various studies [3,16,17] in India have shown that current farmers' yields are quite low and there are large yield gaps between current farmers' yields and potentially achievable yields to the tune of 850 to 1320 kg ha^{-1} in soybean, 1180 to 2010 kg ha^{-1} in groundnut, 610 to 1150 kg ha^{-1} in chickpea, 680 to 1040 kg ha^{-1} in pearl millet, 2560 kg ha^{-1} in rice, and 70 kg ha^{-1} in wheat. A long term experiment (since 1976) at ICRISAT center based at Patancheru, India has demonstrated a virtuous cycle of persistent yield increases up to 5 times through improved land, water and nutrient management in rainfed agriculture [1,12,18]. So there is clear evidence of large gaps between actual and attainable yields, which suggest an urgent need for boosting financial and technical investments to sustainably intensify SAT regions and address the issues of poverty, food security and nutrition.

4. Soil degradation holding back the achievable yields in the Indian SAT

In the semi-arid tropics (SAT), soil fertility related degradation (19, 20, 21] in addition to water scarcity has been identified as the main cause for low crop yields and inefficient utilization of even existing water resources. Rainfed soils are multi nutrient deficient and need proper nutrient management strategies to bridge the existing gap between farmers' current yields and achievable potential yields (19, 20, 21). In view of observed deficiencies of major nutrients nitrogen (N), phosphorus (P) and potassium (K), their application as currently practiced is important for the SAT soils [22–24], but very little attention has been paid to diagnose and take corrective measures for emerging widespread deficiencies of secondary and micro nutrients in various crop production systems [20,21,25–27] followed in millions of small and marginal farmers' fields in the SAT. This corrective fertilizer management strategy to address soil fertility related degradation apparently is the key to realize achievable yields.

5. Rainy season fallows: opportunities to boost production in Central Indian SAT

There are regions in Madhya Pradesh where no crop is grown during rainy season called as rainy season fallows or rainy fallows. Three fundamental barriers to cropping in black soil region are; (1) threat of flooding of the rainy season crop due to heavy rains, (2) difficulty of soil preparation prior to the monsoon for timely sowing of a rainy season crop, and (3) reduction in available soil moisture for the post-rainy season crop if a rainy season crop is taken. Traditionally farmers grow a timely secured post-rainy season crop on stored soil moisture and keep the fields fallow during rainy season. It is estimated that 2.02 million ha accounting for 6.57% of the total area of the state remains under rainy season fallows [28,29]. Madhya Pradesh in Central India is endowed with Vertisols (black soils) and associated soils along with assured rainfall (700 to 1200 mm). These soils have poor hydraulic conductivity, and consequently are frequently poorly drained. Studies have proved that Vertisols which have good moisture holding capacity can be used to grow short duration soybean by adopting sound land management practices [12,30]. This will help increase income to farmers besides

Table 1
Detail of important crops in rainfed semi-arid tropics in Madhya Pradesh, India during 2011-12.

Crop	India			Madhya Pradesh				
	Area (million ha)	Production (million t)	Productivity (kg ha^{-1})	Area (million ha)	% of India area	Production (million t)	% of India production	Productivity (kg ha^{-1})
Soybean	10.2	12.3	1200	5.67	56	6.28	51	1110
Groundnut	5.31	6.93	1310	0.21	4	0.34	5	1620
Rapeseed & mustard	5.92	6.78	1150	0.79	13	0.87	13	1110
Chickpea	8.32	7.58	910	3.04	37	3.29	43	1080
Wheat	30.0	94.0	3140	4.89	16	10.6	11	2160
Maize	8.71	21.6	2480	0.86	10	1.29	6	1490
Rice	44.0	104.3	2370	1.66	4	1.84	2	1110
Coarse cereals	26.4	42.0	1590	1.77	7	2.47	6	1400

Source: [5].

preventing land degradation due to runoff erosion. The land management practices like conservation furrow (CF) at 3 to 4 m interval or broad bed and furrow (BBF) landform system comprising of 1 m raised bed followed by 0.50 m furrow can effectively address the existing barriers to cultivating rainy fallows through – effectively draining excess water via furrows; enable land preparation by providing compact furrows to move on while keeping intact the surface bed soil; and infiltering and storing more soil water through intact surface bed soil.

6. Methodology for on-farm impact

6.1. Diagnosis of soil health issues and development of fertilizer recommendations

The target eco-regions for this study were the dryland areas of Madhya Pradesh state in India comprising the districts of Barwani, Guna, Indore, Jhabua, Mandla, Raisen, Rajgarh, Sagar, Sehore, Shajapur and Vidisha. The predominant soils of target regions are Vertisols varying in soil depth. To diagnose soil fertility related constraints, 317 soil samples were collected from farmers' fields in target ecoregions by adopting participatory stratified soil sampling method [27,31]. In addition to hitting at technical constraints in the region, a farmer participatory strategy in soil sampling/analysis and evaluation of analysis based fertilization was particularly emphasized to inculcate a sense of ownership among the farmers, a lack of which has failed many supply driven institutional developmental initiatives in the past. Under this method, we divided target ecoregions in the districts into three topo-sequences. At each topo-sequence location, samples were taken proportionately from small, medium and large farm-holding sizes to address the variations that may arise due to different management because of different economic status in each farm size class. Within each farm size class in a topo-sequence, the samples were chosen carefully to represent all possible soil fertility variations as judged from soil colour, texture, cropping system and agronomic management. At ultimate sampling unit in a farmer's field, we collected 8 to 10 cores of surface (0–0.15 m) soil samples and mixed together to make a composite sample. In view of high costs involved in soil sampling and analysis, this method is very suited as few samples efficiently represent the sampled area while does not compromise with the accuracy of the results. The collected soil samples were processed and analysed at ICRISAT for soil organic carbon (org C) and available contents of P, K, sulphur (S), boron (B) and zinc (Zn) following the standard procedures and as described in Girish Chander et al. [32].

Based on soil analysis results and variable soil fertility across the region, the fertilizer recommendations were developed at the level of cluster of villages called block, a lower administrative unit in a district. We recommended to apply full dose of a particular nutrient (N, P, K, S, B, Zn) if deficiency was on >50% farms in a block and half dose of a nutrient if its deficiency was on < 50% farms. This way of nutrient recommendation was adopted to manage existing risks in rainfed agriculture in the SAT while targeting optimum yields to improve livelihoods of poor SAT farmers. The critical values for delineating deficiency were 5.0 g kg^{-1} for organic C, 11.2 kg ha^{-1} for P, 112 kg ha^{-1} for K, 22.4 kg ha^{-1} for S, 1.30 kg ha^{-1} for B and 1.68 kg ha^{-1} for Zn [19].

6.2. Farmer participatory research for impact with soil test based balanced nutrition

Participatory trials were conducted with prominent crops on farmers' fields during the rainy (June to September) seasons of 2011 and 2012, and post-rainy (Oct-Nov to Jan-Feb) seasons of 2010-11 and 2011-12. On-farm trials were conducted to evaluate the soil test based balanced nutrition. There were two treatments added and evaluated on new farms every season;

(1) FP (farmers' practice): application of N, P and K plus 2 t ha^{-1} farmyard manure only, and
(2) BN (balanced nutrition): comprising of FP inputs plus S, B and Zn

Full dose of inputs under farmers practice varied from 50 to 80 kg N ha^{-1} and 30 to 40 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} in non-legumes and 10 to 20 kg N ha^{-1}, 25 to 60 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1} in legume crops. The BN treatment contained in addition to N, P and K, the deficient S, B and Zn, and the full dose consisted of 30 kg S ha^{-1}, 10 kg Zn ha^{-1} and 0.5 kg B ha^{-1} [25]. The nutrient/fertilizer recommendations were adjusted at block level in the districts as explained in previous section. The fertilizer sources for nutrients were urea for N, DAP (diammonium phosphate) for P and N, MOP (muriate of potash) for K, gypsum for S, zinc sulphate for Zn and agribor (20% B) for B. The treatments were imposed on 2000 m^2 plots without replicates on a farm, side by side and uniform crop management practices were ensured in both the treatments viz. FP and BN. Application of all nutrients were made basal except N in non-legumes of which 50% was added as basal and the remaining in two equal splits at one month interval.

The residual benefits of S, B, Zn as BN added during previous 3 seasons (post-rainy 2010-11, rainy 2011 and post-rainy 2011-12) were also evaluated during the rainy season 2012 by monitoring yields in FP and BN treatments.

6.3. Farmer participatory research for impact with rainy season fallow management

Participatory trials were conducted on farmers' fields in rainy season fallow regions in Madhya Pradesh during the rainy season 2010. The two landform management practices evaluated were, (i) Conservation furrow (CF) (after 3-4 meters distance) and (ii) Broadbed and furrow (BBF) (1 m raised bed followed by 0.50 m furrow). Soil test based balanced nutrition (N, P, K plus S, B and Zn) and other agronomic practices were common in both the treatments as has been explained earlier.

During the succeeding post-rainy season, the yields in rainy fallow managed plots were also compared with the farmers' practice of taking only one post-rainy season crop by recording yields in all the 3 treatments.

6.4. *Estimation of benefits under improved management*

To evaluate the benefits of soil test based fertilization, crop yields were recorded at maturity, both from the FP and BN plots. The additional cost on fertilizer application under BN was worked out on prevailing average market prices of fertilizers used viz. 33 Rs kg^{-1} zinc sulphate, 120 Rs kg^{-1} agribor and 2.20 Rs kg^{-1} gypsum. Additional returns were calculated for crops based on farm gate price of 23 Rs kg^{-1} soybean, 37 Rs kg^{-1} groundnut, 30 Rs kg^{-1} chickpea, 12 Rs kg^{-1} maize and 13 Rs kg^{-1} wheat. The benefit to cost ratios were worked out by dividing additional returns through higher yields with additional costs of S, B and Zn in BN over and above the FP. The data collected were subjected to statistical analysis with ANOVA to test the least significant difference of treatment means at 5% level using the Genstat 13th edition [33]. Each farmer's field in a district was treated as replication for statistical analysis of the data.

7. Findings and impact

7.1. *Extensive soil health degradation*

A soil health assessment of crop fields across districts in Madhya Pradesh showed precisely a variable soil fertility in respect of plant nutrients and rampant deficiencies of secondary and micronutrients. The results showed 47 to 100% fields having adequate levels of soil organic C (Table 4). Except Sehore district, most (>50%) fields in general were sufficient in soil organic C, and thus indicated sufficient available N also. Similarly, most fields (55 to 75%) in Indore, Jhabua and Shajapur had adequate P levels; while the rest districts of Barwani, Guna, Mandla, Raisen, Rajgarh, Sagar, Sehore and Vidisha had only 8 to 40% fields with adequate levels of available P, indicating thus, deficiency in most of the fields. Available K was sufficient in 95 to 100% fields and so not really a limiting nutrient to productivity enhancement. Across the districts, relatively few fields in general had adequate levels of S and micronutrients B and Zn or in other words deficiency in most fields, which farmers are not aware of and that is not part of their fertilizer management practices, and so apparently holding back the realization of higher yields. Specifically, S was in adequate amounts in most fields in Indore (91% fields) and Shajapur (75% fields), but in rest of 9 districts only 4 to 47% fields had adequate S. Similarly, B was in adequate amounts in most fields in Indore (83% fields), while the rest 10 districts had only 5 to 50% fields with adequate B levels. Micronutrient Zn was in adequate amounts in most fields (60 to 95%) in Indore, Jhabua, Rajgarh, Sagar and Shajapur; while few fields (3 to 48%) had adequate Zn in Barwani, Guna, Mandla, Raisen, Sehore and Vidisha.

Similar soil fertility related degradation have been reported in other rainfed SAT regions of India [19–21].

Table 2.

7.2. *Soil test-based balanced nutrition for economic productivity improvement*

In Madhya Pradesh, the soil test based BN management benefited farmers through significantly increased rainy season crop productivity over the FP during both the years 2011 and 2012 – 6 to 24% in soybean, 10 to 12% in maize, and 8 to 29% in groundnut (Table 3). Similarly during the post-rainy seasons, the productivity improved by 9 to 45% in chickpea and 5 to 30% in wheat (Table 4). An economic assessment for both the years showed that for adopting soil test based BN, per rupee invested additionally on the application of S, B and Zn got additional returns by Rs 1.10 to Rs 10.7, so proving it an economically remunerative option. Therefore, soil test-based fertilization is a way forward not only for sustainable intensification, but also to improve farm based livelihoods and bring in social equity. Rainfed crops in other parts of India have also shown positive response to BN [19,21,32]. Moreover, the soil fertility management through BN enabled crop plants to produce more food per drop of same available water, and so is one of the most important rainwater management strategies also to improve water productivity [11], in the water scarce SAT regions.

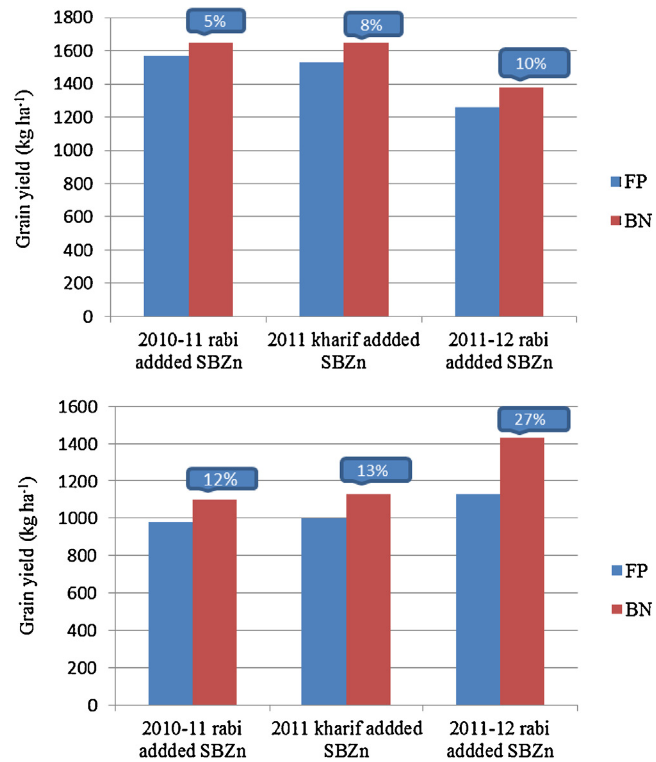

Figure 1. Residual benefits of applied S + B + Zn (BN) in soybean grain yield over the famers' practice (FP) in Madhya Pradesh, rainy season 2012- Above: Shajapur district; Bottom: Jhabua district (Per cent values above bars indicate increase in yield over FP).

7.3. *Resilience building and residual benefits through secondary and micronutrients*

In Madhya Pradesh, the plots with applied S, B, Zn in BN during the post-rainy season 2010-11, rainy season 2011 and post-rainy season 2011-12 showed significant residual benefits during the rainy season 2012 (Figure 1). In Shajapur district, the residual benefits were to the tune of 10% after one season, 8% after two seasons and 5% after three seasons. Similarly, in Jhabua district, the residual benefits were to the tune of 27% after one season, 13% after two seasons and 12% after three seasons. In economic terms, BN strategy produced more food worth 1840 Rs ha^{-1} to 2760 Rs ha^{-1} under the BN treatment during each of the succeeding season in Shajapur district. Similarly in Jhabua district, BN strategy produced more food worth 2760 Rs ha^{-1} to 6900 Rs ha^{-1} under the BN treatment during each of the succeeding season. The results clearly showed that BN is not only economically remunerative in the season-1 of application, but also leads to resilience building of production systems

Table 2
Soil health status of farmers' fields indicating sufficiency/adequacy of essential nutrients in Madhya Pradesh state of India.

District	Block	No. of farmers	% adequacy in available nutrients (mean; range of available contents[a])					
			Org C	P	K	S	B	Zn
Barwani	Barwani	20	55 (5.10; 2.8-7.6)	**30** (10.4; 1.12-41.2)	100 (328; 164-670)	**45** (26.4; 8.96-90.7)	**20** (0.95; 0.40-1.57)	**25** (1.29; 0.67-2.55)
Guna	Madusudangarh	38	79 (6.53; 4.7-11.1)	**21** (7.13; 0.22-22.9)	100 (354; 193-679)	**13** (14.0; 6.05-32.0)	**50** (1.49; 0.49-4.93)	**5** (1.13; 0.54-3.90)
Indore	Samer	23	91 (6.56; 4.3-10.8)	61 (23.4; 1.12-94.5)	100 (589; 289-1604)	91 (66.5; 13.2-301)	83 (1.83; 1.03-2.91)	78 (2.48; 1.25-6.72)
Jhabua	Meghnagar	22	100 (8.75; 5.8-15.3)	55 (21.8; 0.45-94.5)	100 (484; 197-1133)	**5** (14.2; 6.05-63.2)	**9** (0.89; 0.58-1.70)	95 (3.45; 1.48-7.12)
Mandla	Nivas	21	86 (6.75; 4.5-12.5)	**10** (6.27; 2.24-16.1)	100 (319; 184-643)	**10** (10.8; 4.48-29.6)	**14** (0.65; 0.13-1.79)	**48** (1.76; 1.08-2.55)
Raisen	Silwani	20	70 (5.83; 4.2-9.7)	**10** (6.98; 1.12-30.0)	100 (445; 264-616)	**10** (13.8; 6.50-28.7)	**10** (0.79; 0.45-1.66)	**10** (1.10; 0.67-2.20)
Rajgarh	Rajgarh	30	87 (7.79; 4.4-14.1)	**40** (12.8; 3.58-43.0)	100 (454; 114-972)	**47** (27.6; 6.50-113)	**27** (1.10; 0.67-2.06)	73 (2.56; 0.85-8.56)
Sagar	JC Nagar	32	91 (7.18; 4.2-21.9)	**22** (15.9; 1.12-152)	100 (593; 334-746)	**37** (22.5; 9.41-52.0)	**9** (0.81; 0.40-2.73)	66 (2.33; 1.12-6.94)
Sehore	Sehore	19	**47** (5.03; 3.6-6.9)	**16** (8.97; 1.12-38.5)	95 (375; 108-573)	**26** (18.5; 6.72-45.9)	**5** (0.88; 0.63-1.39)	**5** (1.18; 0.81-2.06)
Shajapur	Agar	20	90 (8.17; 4.6-11.5)	75 (19.4; 2.24-57.8)	100 (269; 114-558)	75 (38.6; 12.5-94.1)	**20** (0.97; 0.40-1.61)	60 (1.90; 1.03-3.18)
Vidisha	Vidisha/Lateri	72	68 (5.56; 3.1-9.2)	**8** (6.29; 1.12-31.6)	100 (454; 215-898)	**4** (12.4; 4.03-37.2)	**7** (0.79; 0.27-1.66)	**3** (0.77; 0.22-2.24)

[a] Values in () indicate the mean and range of available contents in kg ha^{-1} for all parameters except organic C in g kg^{-1}.

Table 3
Soil test-based balanced nutrient management improved rainy season crop grain/pod yield and benefits under rainfed conditions in Madhya Pradesh, India.

District	Crop	Grain/pod yield (kg ha^{-1})									
		2011					2012				
		No. of trials	FP	BN	LSD (5%)	B:C ratio	No. of trials	FP	BN	LSD (5%)	B:C ratio
Guna	Soybean	4	1470	1680	156.7	2	6	800	930	78.9	1.3
Indore	Soybean	62	2010	2140	53.3	2.5	28	1830	1950	14.1	2.3
Jhabua*	Soybean	23	1020	1170	18.9	2.2	21	1150	1370	51.7	3.2
Sehore	Soybean	21	1210	1410	14.3	1.9	20	1530	1760	43.2	2.2
Shajapur	Soybean	60	720	800	9.55	1.4	70	1540	1660	29.6	2.1
Vidisha	Soybean	14	1120	1390	98.6	2.6	15	1380	1670	39.8	2.8
Barwani	Maize	3	2150	2400	-	1.3	12	3450	3810	54.6	1.8
Barwani	Groundnut	3	1650	1900	-	3.9	2	1130	1350	31.8	3.4
Sagar	Groundnut	4	1300	1410	280.1	2.6	3	1480	1910	71.7	10.2

Note: FP = Farmers' practice (application of N, P, K only); BN = Balanced nutrition (FP inputs plus S, B, Zn); B:C = Benefit to cost ratio; *Source: [21].

Table 4
Soil test-based balanced nutrient management improved post-rainy season crop grain yield and benefits under rainfed conditions in Madhya Pradesh, India.

District	Crop	Grain yield (kg ha^{-1})									
		2010-11					2011-12				
		No. of trials	FP	BN	LSD (5%)	B:C ratio	No. of trials	FP	BN	LSD (5%)	B:C ratio
Guna	Chickpea	25	1150	1400	210.9	3.1	4	1310	1430	76.2	1.5
Jhabua	Chickpea	7	880	1170	51.8	5.6	5	1160	1220	27.8	1.2
Raisen	Chickpea	35	1050	1270	59.7	2.8	45	1560	2020	55.4	5.8
Sagar	Chickpea	14	1060	1260	124.4	3.8	54	1640	2030	41.2	7.5
Shajapur	Chickpea	8	1260	1490	28.4	5.1	13	1060	1540	23.2	10.7
Vidisha	Chickpea	10	1230	1460	213.8	2.9	7	1190	1540	214	4.4
Guna	Wheat	40	2580	2870	247.7	1.6	62	3730	3930	37.7	1.1
Raisen	Wheat	12	1930	2270	196.1	1.8	47	2610	3400	129	4.3
Sagar	Wheat	9	1910	2210	142.1	2.5	54	2610	3280	79.5	5.6

Note: FP = Farmers' practice (application of N, P, K only); BN = Balanced nutrition (FP inputs plus S, B, Zn); B:C = Benefit to cost ratio.

apparently through improved soil health which is manifested as yield benefits in succeeding seasons.

7.4. Landform management and balanced nutrition for cultivating rainy season fallows

In rainy fallow regions, landform management coupled with soil test based balanced fertilization enabled farmers to grow and harvest good soybean yields during the rainy season 2010 (Table 5). The BBF landform management tended to prove superior over the CF. In the same plots, after taking rainy season crop with recommended technology, post rainy wheat and chickpea crops were also grown. The data (Figure 2) showed increased wheat and chickpea grain yields in rainy fallow managed plots as compared to FP of growing only one crop (wheat or chickpea) in post-rainy season. These results are expected due to improved soil health as a result

Table 5
Effects of landform management and balanced nutrition on soybean yield in rainy season fallow regions in Madhya Pradesh, rainy season 2010.

District	Crop	No. of trials	Grain yield (kg ha^{-1})		LSD (5%)	Straw yield (kg ha^{-1})		LSD (5%)
			CF+BN	BBF+BN		CF+BN	BBF+BN	
Guna	Soybean	21	1350	1450	210	2110	2310	226
Raisen	Soybean	26	1270	1360	59	1930	2300	70
Indore	Soybean	5	1600	1700	231	1730	1810	158
Vidisha	Soybean	5	1340	1520	511	1440	1830	748

Note: CF = Conservation furrow at 4-5 m distance; BBF = Broad bed and furrow (1 m raised bed followed by 0.50 m furrow); BN = Balanced nutrition (N, P, K plus S, B, Zn).

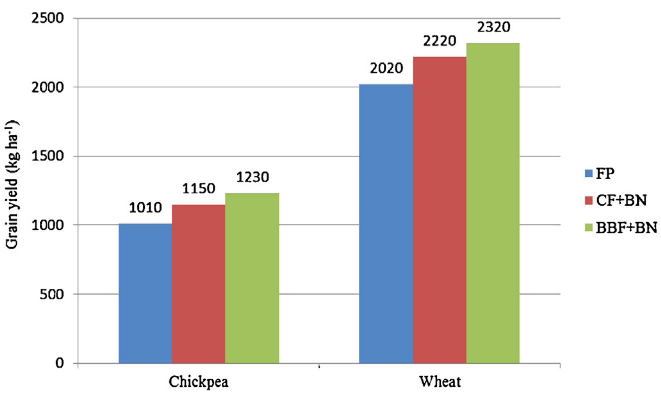

Figure 2. Improved management (CF + BN or BBF + BN) in rainy fallows benefitted succeeding chickpea and wheat over FP of sole crop in post-rainy season in Raisen district, Madhya Pradesh, post-rainy season 2010-11.

of soil test-based balanced nutrition during rainy season and more of moisture storage due to appropriate landform management.

8. Conclusions

Farmers' crop yields in rainfed semi-arid tropics (SAT) of Madhya Pradesh, India are very low as compared to achievable potential. Diagnostic soil fertility assessment revealed widespread deficiencies of S, B and Zn along with that of P which are apparently holding back the productivity potential in Madhya Pradesh. Currently farmers are unaware of the deficiencies of S, B and Zn and do not consider them in their fertilization management practices which is a biggest threat for the sustainability of crop production. The apparent yield losses in absence of soil test based BN practices are between 5 to 45% of current crop yield levels in the season-1 and between 5 to 27% in each of the next 3 succeeding seasons. Soil test-based balanced nutrition along with appropriate landform management like broad bed and furrow or conservation furrow can enable soybean cultivation in 2 million ha fallow land. These results indicate a need for desired policy orientation by the respective governments to promote soil test-based BN and landform management practices to improve productivity and livelihoods of smallholders in the semi-arid tropics of India.

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References

[1] S.P. Wani, Y. Dixin, Z. Li, W.D. Dar, G. Chander, Enhancing agricultural productivity and rural incomes through sustainable use of natural resources in the semi-arid tropics, J. Sci. Food Agric. 92 (2012) 1054–1063.
[2] S.P. Wani, T.K. Sreedevi, K.L. Sahrawat, Y.S. Ramakrishna, Integrated watershed management – a food security approach for SAT rainfed areas, J. Agromet. 10 (2008) 18–30.
[3] V.S. Bhatia, Piara Singh, S.P. Wani, A.V.R. Kesava Rao, K. Srinivas, Yield gap analysis of soybean, groundnut, pigeonpea and chickpea in India using simulation modeling, Global Theme on Agroecosystems Report No. 31, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2006.
[4] U.A. Amarasinghe, T. Shah, H. Turral, B.K. Anand, India's water future to 2025-2050: business-as-usual scenario and deviations, IWMI Research Report 123, International Water Management Institute (IWMI), Colombo, Sri Lanka, 2007.
[5] Ministery of Agriculture, Government of India, Agricultural Statistics at a glance 2012, [Internet] Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, India, Available from: http://eands.dacnet.nic.in/latest_2006.htm [Accessed April 2013], 2013.
[6] FAOSTAT, [online] Available from: http://faostat.fao.org/site/550/default.aspx#ancor, 2013.
[7] World Bank, Agricultural growth for the poor: an agenda for development, The International Bank for Reconstruction and Development, Washington, DC, 2005.
[8] X. Irz, T. Roe, Can the world feed itself? Some insights from growth theory, Agrekon 39 (2000) 513–528.
[9] C. Thirtle, L. Beyers, L. Lin, V. McKenzie-Hill, X. Irz, S. Wiggins, J. Piesse, The impacts of changes in agricultural productivity on the incidence of poverty in developing countries, DFID Report No. 7946, Department for International Development (DFID), London, 2002.
[10] J. Rockstrom, N. Hatibu, T. Oweis, S.P. Wani, Managing water in rainfed agriculture, in: D. Molden (Eds.), Water for food, water for life: a comprehensive assessment of water management in agriculture, Earthscan, London, 2007, pp. 315-348.
[11] J. Rockström, L. Karlberg, S.P. Wani, J. Barron, N. Hatibu, T. Oweis, A. Bruggeman, J. Farahani, Z. Qiang, Managing water in rainfed agriculture-the need for a paradigm shift, Agric. Water Manag. 9 (2010) 543–550.
[12] S.P. Wani, P. Pathak, L.S. Jangawad, H. Eswaran, Piara Singh, Improved management of Vertisols in the semi-arid tropics for increased productivity and soil carbon sequestration, Soil Use Manag. 19 (2003) 217–222.
[13] S.P. Wani, H.P. Singh, T.K. Sreedevi, P. Pathak, T.J. Rego, B. Shiferaw, S.R. Iyer, Farmer-participatory integrated watershed management: adarsha watershed, Kothapally India- an innovative and upscalable approach, in: R.R. Harwood, A.H. Kassam, Research towards integrated natural resources management: examples of research problems, approaches and partnerships in action in the CGIAR. Consultative Group on International Agricultural Research (CGIAR), Washington D.C, USA, and Food and Agriculture Organization (FAO), Rome, Italy, 2003b, pp. 123-147.
[14] S.P. Wani, T.K. Sreedevi, J. Rockstrom, Y.S. Ramakrishna, Rainfed agriculture - past trends and future prospects, in: S.P. Wani, John Rockstrom, Theib Oweis (Eds.), Rainfed agriculture: unlocking the potential, CAB International, Wallingford, UK, 2009, pp. 1–35.
[15] S.P. Wani, Girish Chander, K.L. Sahrawat, S. Dixit, B. Venkateswarlu, Improved crop productivity and rural livelihoods through balanced nutrition in the rain-fed semi-arid tropics, Resilient Dryland Systems Report No. 58, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2013.
[16] M.V.R. Murty, Piara Singh, S.P. Wani, I.S. Khairwal, K. Srinivas, Yield gap analysis of sorghum and pearl millet in India using simulation modeling, Global Theme on Agroecosystems Report No. 37, International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2007.
[17] P.K. Aggarwal, K.B. Hebbar, M.V. Venugopalan, S. Rani, A. Bala, A. Biswal, S.P. Wani, Quantification of yield gaps in rain-fed rice, wheat, cotton and mustard in India, Global Theme on Agroecosystems Report No. 43, International Crops

Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2008.
[18] S.P. Wani, J. Rockström, B. Venkateswarlu, A.K. Singh, New paradigm to unlock the potential of rainfed agriculture in the semi-arid tropics, in: R. Lal, B.A. Steward (Eds.), World soil resources and food security, CRC Press, Boca Raton, Fl, USA, 2011, pp. 419–470.
[19] K.L. Sahrawat, S.P. Wani, G. Parthasaradhi, K.V.S. Murthy, Diagnosis of secondary and micronutrient deficiencies and their management in rainfed agroecosystems: case study from Indian semi-arid tropics, Commun. Soil Sci. Plant Anal. 4 (2010) 346–360.
[20] S.P. Wani, K.L. Sahrawat, K.V. Sarvesh, Baburao Mudbi, K. Krishnappa, Soil fertility atlas for Karnataka, India, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2011b.
[21] G. Chander, S.P. Wani, K.L. Sahrawat, L.S. Jangawad, Balanced plant nutrition enhances rainfed crop yields and water productivity in Jharkhand and Madhya Pradesh states in India, J. Trop. Agric. 50 (2012) 24–29.
[22] S.A. El-Swaify, P. Pathak, T.J. Rego, S. Singh, Soil management for optimized productivity under rainfed conditions in the semi-arid tropics, Adv. Soil Sci. 1 (1985) 1–64.
[23] T.J. Rego, V.N. Rao, B. Seeling, G. Pardhasaradhi, J.V.D.K. Kumar Rao, Nutrient balances - a guide to improving sorghum and groundnut-based dryland cropping systems in semi-arid tropical India, Field Crops Res. 81 (2003) 53–68.
[24] K.L. Sharma, J.K. Grace, K. Srinivas, Influence of tillage and nutrient sources on yield sustainability and soil quality under sorghum-mung bean system in rainfed semi-arid tropics, Commun. Soil Sci. Plant Anal. 40 (2009) 2579–2602.
[25] T.J. Rego, S.P. Wani, K.L. Sahrawat, G. Pardhasaradhi, Macro-benefits from boron, zinc and sulfur application in Indian SAT: a step for grey to green Revolution in agriculture, Global Theme on Agroecosystems Report No. 16, International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2005.
[26] K.L. Sahrawat, S.P. Wani, T.J. Rego, G. Pardhasaradhi, K.V.S. Murthy, Widespread deficiencies of sulphur, boron and zinc in dryland soils of the Indian semi-arid tropics, Curr. Sci. 93 (2007) 1428–1432.
[27] K.L. Sahrawat, S.P. Wani, A. Subba Rao, G. Pardhasaradhi, Management of emerging multinutrient deficiencies: a prerequisite for sustainable enhancement of rainfed agricultural productivity, in: S.P. Wani, J. Rockstrom, K.L. Sahrawat (Eds.), Integrated Watershed Management, CRC Press, The Netherlands, 2011, pp. 281–314.
[28] S.P. Wani, R.S. Dwivedi, K.V. Ramana, A. Vadivelu, R.R. Navalgund, A.B. Pande, Spatial distribution of rainy season fallows in Madhya Pradesh: potential for increasing productivity and minimizing land degradation, Global Theme 3: Water, Soil, and Agrobiodiversity Management for Ecosystem Health Report No. 3, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2002.
[29] T.K. Sreedevi, S.P. Wani, A.V.R. Kesava Rao, P. Singh, I. Ahmed, New science tools for managing community watersheds for enhancing impact, J. SAT Agric. Res. 7 (2009) 1–19.
[30] R.S. Dwivedi, K.V. Ramana, S.P. Wani, P. Pathak, Use of satellite data for watershed management and impact assessment, in: S.P. Wani, A.R. Maglinao, A. Ramakrishna, T.J. Rego (Eds.), Integrated watershed management for land and water conservation and sustainable agricultural production in Asia: proceedings of the ADB-ICRISAT-IWMI project review and planning meeting, 10-14 December 2001, Hanoi, Vietnam, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, 2003, pp. 149-157.
[31] K.L. Sahrawat, T.J. Rego, S.P. Wani, G. Pardhasaradhi, Stretching soil sampling to watershed: evaluation of soil-test parameters in a semi-arid tropical watershed, Commun. Soil Sci. Plant Anal. 39 (2008) 2950–2960.
[32] G. Chander, S.P. Wani, K.L. Sahrawat, P.J. Kamdi, C.K. Pal, D.K. Pal, T.P. Mathur, Balanced and integrated nutrient management for enhanced and economic food production: case study from rainfed semi-arid tropics in India, Arch. Agron. Soil Sci. (2013), http://dx.doi.org/10.1080/03650340.2012.761336.
[33] C. Ireland, Experimental statistics for agriculture and horticulture, Chelmsford, Essex, UK, 2010.